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IMPROVEMENT OF SWEET PEPPER (*Capsicum annuum* L.) PRODUCTIVITY USING SOME ANTIOXIDANTS UNDER SALINITY CONDITIONS OF SOUTH SINAI

I. MORPHOLOGICAL GROWTH CHARACTERS

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ABSTRACT

Two field experiments were conducted during summer seasons of each 2012 and 2013 in the Ras-Suder Research Station, South Sinai, Desert Research Center. The main object of this research was studying the effect of some antioxidant treatments on morphological growth characters of sweet pepper plant (*Capsicum annuum* L.) hybrid cultivar "Sonar". Aqueous solutions of antioxidants were used as foliar spray; *viz*., ascorbic acid (Vitamin C), oxalic acid, salicylic acid and, tocopherol (Vitamin E) within four different concentrations of these antioxidants (0.0, 200, 400 and 600 ppm) were applied at 20, 40 and 60 days after transplanting. Obtained results reflected that the highest values of growth parameters expressed as plant height, number of branches and leaves per plant, fresh and dry weight per plant and leaf area per plant as well as reading total chlorophyll were significantly affected by antioxidants, the highest values were recorded spraying with salicylic acid and ascorbic acid at 400 ppm.

Key words: Ascorbic acid, oxalic acid, salicylic acid, tocopherol, growth, sweet pepper.

INTRODUCTION

Sweet Pepper (*Capsicum annuum* L.) is an important vegetable crop, not only because of its economic importance, but also for the nutritional value of its fruits, mainly due to the fact that it is an excellent source of natural colures and antioxidant compounds **(Howard *et al*, 2000).** Pepper fruits considered an excellent source of bioactive nutrients such as carotenoids, vitamin C and phenolics compounds **(Navarro *et al*., 2006).**

The sequence of events in the plant tissue subjected to salinity stress increased the production of Reactive Oxygen Species (ROS) and of oxidized target molecules, increases in the levels of anti-oxidative systems and antioxidants also increased scavenging capacity for ROS, resulting in tolerance against the salinity stress **(Mano, 2002).** Ascorbic acid is an important antioxidant has been shown to protect plants. Vitamin C led to increase nucleic acid content especially RNA. Vitamin C functions as antioxidant, an enzyme factor and as growth regulating factor. It plays an important role in different processes, including photosynthesis, photo protection, cell wall growth and cell expansion resistance to environmental stresses of, synthesis of ethylene, gibberellins anthocyanins and hydroxyl proline

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(Nicholas and Wheeler 2000). Smirnoff and Wheeler (2000) reported that ascorbic acid is an abundant component of plants. It reaches a concentration of over 20 mM in chloroplasts and occurs in all cell compartments including cell wall.

Oxalic acid is a common constituent of plant, and several species accumulate high levels of the simplest dicarboxylic acid. The most striking chemical property of oxalic acid is its strong chelating ability with multivalent cations. Recently, oxalic acid application has received much attention in relation to induced disease systemic resistance and its antioxidant capability **(Zhang *et al*., 1999; Malencic *et al*., 2004).**

Salicylic acid has numerous functions, particularly the inhibition of germination and growth, interference with root absorption, reduced transpiration and leaf abscission. Salicylic acid is widely present in plant and functions as a hormonal mediator of the systemic acquired resistance response. Thus, it presents in a large scale of fruits, vegetable, herbs and spices of dietary relevance.

Salicylic acid as plant phenolic is now considered as a hormone-like endogenous regulator, and has a role in the defence mechanisms against biotic and unbiotic stressors has been well documented **(Yalpani *et al*., 1994).** SA potentials the generation of reactive oxygen species in photosynthetic tissues during salt and osmotic stresses **(Borsani *et al*., 2001).** It plays a vital role in plant growth, ion uptake and transport. Tocopherol (Vitamin E) is an essential vitamin for humans and animals, it is exclusively synthesized in photosynthetic organisms **(DellaPenna, 2005)**. Phytoregulator compounds (Vitamin E) suggested to elevate and tolerate the adverse effects of biotic and unbiotic stresses such as moisture and salt stress on plant growth and yield **(Demiral and Turkan 2005; Raja Babo *et al*., 2005).**

The main objective of this research was to study the effect of applying some antioxidants on sweet pepper (*Capsicum annuum* L., hybrid cultivars "Sonar") to alleviate the harmful effect of salinity under South Sinai conditions.

MATERIALS AND METHODS

A field experiment was carried out during the summer season of each 2012 and 2013 at The Experimental Farm, Research Station Ras Suder, South Sinai Desert Research Center. The main objective of this research was to study the effect of some antioxidants and their concentrations on increasing resist of pepper plant to alleviate harmful effect of salinity which reflected on morphological growth parameters of sweet pepper plants under sandy loam soil conditions using drip-irrigation system.

The mechanical and chemical analyses of the experimental soil are presented in Table 1. The soil analysis was carried out according to **Richards (1954), Black and Editor (1965) and Jackson (1967).** The hybrid cultivar "Sonar" was used in this study. Seeds of sweet pepper were sown on 10th February in seedling trays under plastic green house conditions. The transplants were set up into the field on 1st of April in both of 2012 and 2013 seasons.

Seedlings were transplanted besides dripper lines, the distance between every two dripper lines were 100 cm. The distance between plants in the same line was 50 cm. The plot area was 12 m^2 (1m width x12 m length). The fertigation method was used in the experiment by water pumped from a well; the analysis of irrigation water is presented in Table 2.The experiment included 16 treatments which were all combinations between 4 antioxidants (ascorbic acid, oxalic acid, Salicylic acid, and Tocopherol) and 4 concentrations (Control, 200 ppm l^{-1}, 400 ppm l^{-1}, and 600 ppm l^{-1}).

Table (1): Chemical properties of the experimental soil.

Depth (cm)	pH	E.C dS/m^{2-}	Saturation soluble extract (mg/100g)							Total nutrients (mg Kg^{-1})			
			Cations			Anions				N	P	K	Fe
			Ca^{++}	Mg^{++}	Na^{+}	Co_3^-	HCO_3^-	So_4^{--}	Cl^-				
0-30	7.7	8.65	24.5	5.2	56.5	0.00	6.0	19.0	61.5	26.0	5.1	51.5	4.2
30-60	7.9	7.35	16.8	3.8	52.4	0.00	3.5	21.0	49.0	23.5	3.4	35.3	3.4

Table (2): Chemical analysis of irrigation water.

pH	EC dS/m^{2-}	Soluble ions (meq.1^{-1})							
		Cations				Anions			
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	HCO_3^-	CO_3^{--}	SO_4^{--}
7.77	7.85	20.5	8.6	48.89	0.35	57.5	5.0	0.0	16.2

The antioxidants were applied as folair spraying on sweet pepper plants three times at 20, 40 and 60 days after transplanting. The design of the experiment in the field was split plot with three replications. Antioxidants were arranged randomly in the main plots, while their concentrations were distributed randomly in sub plots. Conventional culture practices were done as needed and were similar to those used in commercial pepper production in the open field in South Sinai region.

Data recorded

Three plants were randomly taken from each experimental unit. Vegetative growth parameters were recorded three times (30, 50 and, 70 days after transplanting), the following parameters were recorded: Plant height (cm), Number of branch/plant, number of leaves/plant, Branch fresh weight/ plant (g), Leaves fresh weight/ plant(cm), Branch dry weight/plant (g), Leaf dry weight/ plant (g), Leaf area per plant (cm^2), and Total chlorophyll reading (SPAD) chlorophyll was determined in the fourth leaf from pepper plant top using a digital chlorophyll meter, model Minolta Chlorophyll Meter SPAD-502, (Manufactured by Minolta Company, Japan).

Statistical analysis

Statistical analysis of the obtained data was carried out according to Statistical analysis of variance according to **Snedecor and Cochran (1980).** Duncan s multiple range tests was used for comparison among means **(Duncan's, 1958).**

RESULTS AND DISCUSSION

Effect of antioxidants

Plant height and number of both branches and leaves

Concerning the effect of antioxidants data in Table 3 show that application of antioxidant materials; *viz,* ascorbic acid, oxalic acid, salicylic acid and tocopherol affected significantly all studied traits at all

Table (3): Effect of antioxidant on plant height, number of branches and number of leaves of sweet pepper during 2012 and 2013 seasons.

Character / Treatment	Plant height (cm)			No. of branches/ plant			No. of leaves/plant		
	Days after transplanting								
	30	50	70	30	50	70	30	50	70
	First season (2012)								
Ascorbic acid	21.10b	36.97b	43.91a	2.15ab	5.33b	10.63b	35.94a	67.72ab	98.26a
Oxalic acid	18.97c	31.06c	37.80c	1.79b	4.45c	9.51c	32.47b	62.64c	82.32c
Salicylic acid	22.61a	39.19a	45.62a	2.40a	5.79a	11.12a	36.31a	69.87a	99.18a
Tocopherol	20.17bc	35.96b	41.44b	1.90ab	5.42b	9.43c	33.66b	65.98b	89.18b
	Second season (2013)								
Ascorbic acid	21.78b	37.84b	45.45b	2.47a	5.58a	10.88a	37.15ab	70.89b	102.98a
Oxalic acid	19.26c	32.17c	38.43d	1.92b	4.59b	9.42b	32.75c	65.31c	84.87c
Salicylic acid	23.16a	40.21a	47.31a	2.50a	5.94a	11.34a	38.02a	75.69a	106.59a
Tocopherol	20.96b	36.79b	42.86c	1.96b	5.57a	9.65b	34.81bc	70.42b	93.66b

dates in both seasons. The highest values were recorded with application of salicylic acid followed by ascorbic acid and tocopherol, while the lowest value was recorded with application of oxalic acid.

Fresh and dry weight[s] of plant

Data presented in Table 4 show significant differences among antioxidants for fresh and dry weight of branches and leaves of pepper plants. In this respect, application of Salicylic acid had the highest values for all traits followed by ascorbic acid at 30, 50 and 70 days after transplanting in both growing seasons.

Leaf area and total chlorophyll

Data in Table 5 show significant effects for antioxidants on leaf area / plant of sweet pepper. In this respect, application of salicylic acid followed by ascorbic acid had the highest value for leaf area at all sampling dates in both growing seasons. For total chlorophyll (SPAD)' data in the same table show significant effects for antioxidants.

Application of ascorbic acid, salicylic acid and tocopherol recorded the best values in both season. At 70 days from transplanting in the first season the salicylic acid recorded the highest value for total chlorophyll. Whereas, oxalic acid recorded the lowest value for each of leaf area and total chlorophyll in all dates at both seasons.

Effect of antioxidants concentration

Plant height and number of both branches and leaves

As regard to the effect of concentrations of antioxidants, it was found that 400 or 200 ppm had the highest significant value in both seasons followed by 600 ppm and the lowest values were obtained with control treatments for all studied traits; *i.e.,* plant height, number of branches and number of leaves per plant Table 6.

Table (4): Effect of antioxidant on fresh and dry weight of both branches and leaves of sweet pepper during2012 and 2013 seasons.

Character / Treatment	Fresh weight (g)						Dry weight (g)					
	Branches			Leaves			Branches			Leaves		
	Days after transplanting											
	30	50	70	30	50	70	30	50	70	30	50	70
	First season (2012)											
Ascorbic acid	6.36b	24.03b	59.05b	10.56b	42.01b	71.23b	1.87b	5.82a	12.21b	2.25b	6.06b	12.88b
Oxalic acid	4.69d	20.37d	44.00d	9.28c	35.12c	59.62d	1.43d	4.39c	10.76d	1.55d	4.66d	10.33d
Salicylic acid	6.71a	26.53a	60.76a	11.15a	45.87a	74.90a	2.04a	6.13a	12.67a	2.53a	6.81a	13.65a
Tocopherol	5.83c	22.35c	54.84c	9.46c	40.35b	67.45c	1.68c	5.02b	11.56c	1.92c	5.73c	11.74c
	Second season(2013)											
Ascorbic acid	6.71a	24.41b	60.08a	10.96b	42.72	73.12b	1.93b	5.89b	12.41b	2.36b	6.27b	13.42b
Oxalic acid	4.71c	20.93c	44.92c	9.53c	36.44c	60.69d	1.47d	4.41d	10.92d	1.60d	4.75d	10.54d
Salicylic acid	6.88a	26.80a	61.35a	11.81a	46.75a	76.34a	2.16a	6.20a	12.88a	2.69a	7.03a	13.78a
Tocopherol	6.08b	22.55bc	55.51b	9.86c	41.84b	67.84c	1.79c	5.01c	11.74c	1.98c	6.03c	12.28c

Values having the same alphabetical letter (s) did not significantly differ at 0.05 level of significance, according to **Duncan's** multiple range test.

Table (5): Effect of antioxidant on leaf area and total chlorophyll reading (SPAD) of sweet pepper during 2012 and 2013 seasons.

Characters / Treatments	Leaf area/plant (cm^2)			Total chlorophyll reading (SPAD)		
	Days after transplanting					
	30	50	70	30	50	70
	First season (2012)					
Ascorbic acid	338.1ab	1631.8b	3142.8b	69.51ab	71.03a	71.46b
Oxalic acid	277.1c	1327.2c	2101.5c	67.97b	66.39b	67.70d
Salicylic acid	371.3a	1822.4a	3517.1a	70.57a	72.10a	72.30a
Tocopherol	322.9b	1512.4b	2853.2b	69.66ab	69.53ab	70.52c
	Second season (2013)					
Ascorbic acid	359.4ab	1822.9a	2959.9b	69.50a	69.92ab	71.72a
Oxalic acid	290.4c	1443.4b	2021.2d	67.39b	67.67b	68.32b
Salicylic acid	397.6a	2047.8a	3263.1a	70.18a	70.66a	72.03a
Tocopherol	351.6b	1891.6a	2664.4c	69.33a	69.54ab	71.50a

Values having the same alphabetical letter (s) did not significantly differ at 0.05 level of significance, according to **Duncan's** multiple range test.

Table (6): Effect of antioxidant concentrations (ppm) on plant height, number of branches and number of leaves of sweet pepper during 2012 and 2013 seasons.

Character / Treatment	Plant height (cm)			No. of branches/ plant			No. of leaves/plant		
	Days after transplanting								
	30	50	70	30	50	70	30	50	70
	First season (2012)								
0.0	16.97c	29.23c	36.25c	1.65b	4.07d	8.37c	30.24c	51.22c	78.90c
200	22.74a	39.20a	46.10a	2.28a	5.77b	11.29a	36.73a	72.78a	98.88a
400	22.68a	39.86a	46.05a	2.34a	6.16a	11.11a	37.45a	74.04a	102.55a
600	20.46b	34.89b	40.36b	1.99ab	5.00c	9.92b	33.97b	68.16b	88.59b
	Second season (2013)								
0.0	17.34c	30.05c	36.92c	1.62b	4.25c	8.33c	30.70c	52.86c	81.55c
200	23.13a	40.15a	47.18a	2.46a	5.99a	11.58a	38.43a	77.56a	106.38a
400	23.31a	40.90a	47.49a	2.58a	6.30a	11.33a	39.31a	79.44a	108.45a
600	21.38b	35.91b	42.44b	2.20a	5.15b	10.03b	34.29b	72.45b	91.72b

Values having the same alphabetical letter (s) did not significantly differ at 0.05 level of significance, according to **Duncan's** s multiple range test.

Fresh and dry weights of plant

It is obvious from the data presented in Table 7 that spraying with 400 ppm and 200 ppm from any antioxidant had the highest significant values of fresh and dry weights for branches and leaves of sweet pepper in all dates in the first and second seasons.

Leaf area and total chlorophyll

Data in Table 8 show significant effects for antioxidants on leaf area and total chlorophyll of sweet pepper plant. It could be observed from the data that leaf area per pepper plant and total chlorophyll at all sampling dates had the highest values with application of 200 and 400 ppm of any antioxidant in both seasons. At 50 and 70 days from transplanting spraying at 400 ppm had the best value for leaf area and total chlorophyll in both seasons.

Effect of interaction between antioxidants and their concentrations

Plant height and number of both branches and leaves

Data in Table 9 show significant effects for the interaction between foliar spray of antioxidants and their concentrations on plant height, number of branches per plants as well as number of leaves per plant of sweet pepper. The highest values were recorded with application of 400 ppm followed by 200 ppm of Salicylic acid or 400 ppm of ascorbic acid in both seasons at all dates.

Plant fresh and dry weights

The effects of the interaction between antioxidants and their concentrations on the fresh and dry weights; *viz,* branches and leaves of pepper plants are presented in Table 10. All measured parameters gave highly

Table (7): Effect of antioxidant concentrations (ppm) on fresh and dry weight[s] of both branches and leaves of sweet pepper during 2012 and 2013 seasons.

Character / Treatment	Fresh weight (g)						Dry weight (g)					
	Branches			Leaves			Branches			Leaves		
	Days after transplanting											
	30	50	70	30	50	70	30	50	70	30	50	70
	First season (2012)											
0.0	3.63d	18.26d	36.19c	8.39c	30.56c	51.10c	1.12c	3.46c	8.82d	1.32c	4.03d	9.51d
200	6.68b	25.26b	63.56a	10.91a	46.53a	75.68a	2.09a	6.40a	13.15b	2.58a	6.63b	13.34b
400	7.36a	26.91a	63.03a	11.25a	47.12a	77.01a	2.15a	6.56a	13.45a	2.55a	7.21a	14.03a
600	5.91c	22.85c	55.87b	9.92b	40.35b	69.42b	1.66b	4.95b	11.78c	1.81b	5.40c	11.74c
	Second season (2013)											
0.0	3.69c	18.38d	36.75c	8.53c	30.65c	50.95c	1.18c	3.47d	9.03d	1.36c	4.08d	9.63d
200	7.23a	25.79b	64.57a	11.51a	47.77a	77.11a	2.19a	6.45b	13.36b	2.65a	7.02b	13.84b
400	7.53a	27.35a	63.80a	11.70a	48.15a	78.89a	2.24a	6.61a	13.59a	2.68a	7.31a	14.70a
600	5.92b	23.18c	56.74b	10.42b	41.18b	71.04b	1.74b	5.01c	11.97c	1.95b	5.68c	11.84c

Table (8): Effect of antioxidant concentrations (ppm) on leaf area and total chlorophyll reading (SPAD) of sweet pepper during 2012 and 2013 seasons.

Character / Treatment	Leaf are /plant (cm^2)			Total Chlorophyll Reading (SPAD)		
	Days after transplanting					
	30	50	70	30	50	70
	First season (2012)					
0.0	231.1c	926.1d	1854.0c	65.80c	65.75b	66.63c
200	367.8a	1797.2b	3346.5a	71.44a	71.06a	72.01a
400	394.4a	1933.3a	3619.3a	71.27ab	71.98a	73.05a
600	316.0b	1637.3c	2794.7b	69.20b	70.26a	70.30b
	Second season (2013)					
0.0	237.5d	985.9c	1784.8d	65.40c	65.76b	66.86b
200	388.9b	2127.6a	3045.1b	70.67ab	71.04a	72.69a
400	429.8a	2224.7a	3458.4a	71.08a	71.27a	73.00a
600	342.8c	1867.4b	2620.3c	69.24b	69.73a	71.03a

Table (9): Effect of interaction between some antioxidants and their concentrations (ppm) on plant height, number of branches and number of leaves of sweet pepper during 2012 and 2013 seasons.

Character / Treatment		Plant height (cm)			No. of branches/ plant			No. of leaves/plant		
		Days after transplanting								
		30	50	70	30	50	70	30	50	70
		First season (2012)								
Ascorbic acid	0.0	17.8gh	29.03h	36.9gh	1.73ef	4.15f	8.49h	30.27g	51.59i	80.93g-i
	200	22.52d	40.39c	47.40c	2.3b-d	5.66cd	11.53c	37.92b	73.78c-e	102.98cd
	400	23.74c	42.02b	49.43b	2.70ab	6.64b	12.20b	40.87a	77.42b	113.97ab
	600	20.65e	36.45e	41.90ef	1.91d-f	4.86e	10.31e	34.70c	68.11fg	95.16d-f
Oxalic acid	0.0	17.11hi	29.17h	35.85h	1.58f	3.91f	8.54h	29.77g	51.00i	76.56i
	200	20.86e	33.46f	40.66f	2.16c-e	5.01e	10.6de	34.96c	68.22fg	88.42fg
	400	19.53f	31.31g	37.83g	1.76ef	4.67e	9.64f	32.96de	66.63gh	86.00f-h
	600	18.40g	30.32gh	36.9gh	1.66f	4.22f	9.26fg	32.19ef	64.71h	78.29hi
Salicylic acid	0.0	16.22i	29.47h	36.18h	1.70f	4.08f	8.18h	31.07fg	51.86i	79.16hi
	200	24.90b	43.00b	50.73b	2.53a-c	6.00c	12.15b	38.48b	75.01bc	106.55bc
	400	26.71a	47.35a	54.00a	2.93a	7.56a	13.18a	41.07a	81.54a	116.76a
	600	22.63d	36.96e	41.56ef	2.46bc	5.51d	10.99d	34.65c	71.06d-f	94.22d-f
Tocopherol	0.0	17.09hi	29.27h	36.06h	1.58f	4.11f	8.28h	29.84g	50.45i	78.96hi
	200	22.67d	39.95cd	45.62d	2.16c-e	6.41b	10.86d	35.56c	74.11cd	97.55de
	400	20.75e	38.77d	42.94e	1.96d-f	5.75cd	9.44fg	34.89c	70.59ef	93.50ef
	600	20.17ef	35.84e	41.14f	1.91d-f	5.42d	9.15g	34.37cd	68.77fg	86.68f-h
		Second season(2013)								
Ascorbic acid	0.0	17.58i	29.39i	37.3fg	1.75g-i	4.42gh	8.62i	31.12g	52.97g	83.00h
	200	23.22d	41.06c	48.11c	2.66b-d	5.98de	11.73c	39.44c	77.60cd	111.62c
	400	24.3bc	43.93b	51.61b	2.90ab	6.93b	12.59b	42.87b	81.98b	120.26b
	600	21.94e	37.00e	44.68d	2.58b-d	5.01f	10.57e	35.16ef	71.01e	97.03ef
Oxalic acid	0.0	17.04i	30.06hi	36.53g	1.40i	4.33h	8.13j	30.02g	51.99g	80.63h
	200	20.73g	34.18f	41.74e	2.26c-f	5.15f	10.68e	36.30de	73.73de	91.26fg
	400	19.9gh	32.51g	38.50f	2.13e-g	4.75fg	9.69fg	33.40f	69.86e	85.50gh
	600	19.36h	31.92g	36.96g	1.91f-h	4.14h	9.17h	31.30g	65.66f	82.10h
Salicylic acid	0.0	16.91i	30.51h	36.86g	1.70g-i	4.11h	8.33ij	30.97g	52.94g	81.56h
	200	25.27b	43.65b	51.81b	2.70bc	6.23cd	12.58b	40.57c	81.26bc	117.3bc
	400	27.09a	48.02a	55.20a	3.23a	7.63a	13.33a	45.03a	90.64a	130.03a
	600	23.4cd	38.65d	45.36d	2.40c-e	5.81de	11.11d	35.49de	77.93cd	97.46ef
Tocopherol	0.0	17.81i	30.25hi	36.90g	1.66hi	4.16h	8.23ij	30.68g	53.55g	81.00h
	200	23.3cd	41.71c	47.07c	2.23d-f	6.61bc	11.3cd	37.41d	77.65cd	105.32d
	400	21.8ef	39.13d	44.67d	2.06e-h	5.90de	9.73f	35.96de	75.30d	98.01e
	600	20.8fg	36.08e	42.79e	1.90f-h	5.61e	9.29gh	35.21ef	75.20d	90.30g

Values having the same alphabetical letter (s) did not significantly differ at 0.05 level of significance, according to **Duncan's** multiple range test.

Table (10): Effect of interaction between antioxidants and their concentrations (ppm) on fresh and dry weight[s] of both branches and leaves of sweet pepper during 2012 and 2013 seasons

Treatments \ Characters		Fresh weight (g)						Dry weight (g)					
		Leaves			Branches			Leaves			Branches		
		Days after transplanting											
		30	50	70	30	50	70	30	50	70	30	50	70
First season (2012)													
Ascorbic acid	0.0	3.71j	18.20h	36.11k	8.40g	30.66g	50.83h	1.08g	3.33j	8.81k	1.36kl	4.05k	9.65m
	200	7.21c	25.20d	67.59c	11.30c	45.36d	77.75c	2.17c	6.82d	13.3d	2.69d	6.54e	13.9d
	400	8.03b	29.03b	70.40b	12.4b	51.35b	83.44b	2.50b	7.71b	14.7b	3.06c	7.85b	15.6b
	600	6.48e	23.70e	62.11ef	10.2d	40.66e	72.88d	1.73de	5.43f	12.2g	1.91h	5.79g	12.4g
Oxalic acid	0.0	3.65jk	18.06h	35.55k	8.43g	30.50g	51.45h	1.13g	3.52j	8.76k	1.35kl	4.04k	9.42n
	200	5.55g	22.80e	52.07h	10.1d	40.80e	67.39e	1.71e	5.16g	12.41f	1.86h	5.42h	11.21j
	400	5.00h	20.86f	46.26i	9.53e	35.30f	62.16f	1.51f	4.63h	11.29i	1.56j	4.91i	10.6k
	600	4.56i	19.76fg	42.11j	9.10f	33.86f	57.48g	1.38f	4.27i	10.59j	1.44k	4.29j	10.09l
Salicylic acid	0.0	3.63jk	18.63gh	36.25k	8.34g	30.83g	51.17h	1.11g	3.51j	8.84k	1.23m	4.00k	9.6mn
	200	6.83d	27.21c	68.67c	12.1b	51.36b	81.80b	2.43b	7.33c	14.03c	3.19b	7.57c	14.64c
	400	9.86a	34.90a	74.63a	13.17a	56.34a	90.34a	2.78a	8.40a	15.44a	3.57a	9.47a	17.75a
	600	6.52e	25.38d	63.48e	11.00c	44.93d	76.30c	1.86d	5.29fg	12.37f	2.16f	6.19f	12.65f
Tocopherol	0.0	3.53k	18.14h	36.84k	8.38g	30.23g	50.93h	1.13g	3.46j	8.88k	1.33l	4.04k	9.41n
	200	7.15c	25.83d	65.91d	10.2d	48.60c	75.81c	2.07c	6.28e	12.92e	2.58e	7.00d	13.58e
	400	6.57e	22.86e	60.83f	9.92d	45.50d	72.06d	1.81de	5.49f	12.47f	2.04g	6.59e	12.2h
	600	6.07f	22.56e	55.77g	9.36ef	41.96e	71.01d	1.69e	4.83h	12.0h	1.75i	5.32h	11.87i
Second season (2013)													
Ascorbic acid	0.0	3.77i	18.46h	37.15k	8.46j	30.98g	51.53i	1.11h	3.35m	9.03k	1.36j	4.04i	9.78k
	200	7.63c	25.66d	68.89c	11.74c	46.62d	80.15c	2.25c	6.87d	13.5d	2.71d	6.84d	14.25d
	400	8.64b	29.45b	70.99b	12.9b	51.64b	85.30b	2.56b	7.78b	14.7b	3.25c	7.96b	17.19b
	600	6.78d	24.06e	63.30e	10.78f	41.64e	75.50de	1.81de	5.55f	12.5g	2.11f	6.25e	12.48f
Oxalic acid	0.0	3.73i	18.21h	36.33k	8.38j	30.77g	50.13i	1.18h	3.51l	8.88l	1.37j	4.13i	9.67kl
	200	5.64f	23.16ef	53.29h	10.3g	41.63e	68.40f	1.76e	5.19h	12.6g	1.91g	5.85f	11.42h
	400	5.21g	21.46g	47.33i	9.82h	37.40f	64.44g	1.54f	4.63j	11.48i	1.64h	4.72g	10.88i
	600	4.24h	20.99g	42.74j	9.67h	35.96f	59.79h	1.39g	4.29k	10.78j	1.49i	4.30h	10.18j
Salicylic acid	0.0	3.62i	18.56h	36.66k	8.86i	30.06g	51.00i	1.20h	3.59l	9.15k	1.37j	4.13i	9.58l
	200	7.81c	28.06c	69.40c	13.0b	52.86b	83.41b	2.59b	7.40c	14.38c	3.37b	7.93b	14.90c
	400	9.53a	34.88a	75.40a	13.92a	58.01a	91.55a	2.94a	8.49a	15.54a	3.65a	9.71a	17.97a
	600	6.59d	25.70d	63.92e	11.4d	46.08d	79.40c	1.94d	5.34g	12.5g	2.38e	6.34e	12.68e
Tocopherol	0.0	3.66i	18.30h	36.85k	8.42j	30.80g	51.13i	1.25h	3.5lm	9.06k	1.37j	4.03i	9.49l
	200	7.84c	26.26d	66.72d	11.03e	49.98c	76.45d	2.16c	6.36e	13.06e	2.60d	7.45c	14.80c
	400	6.74d	23.60e	61.48f	10.2g	45.55d	74.30e	1.91d	5.55f	12.67f	2.18f	6.82d	12.78e
	600	6.07e	22.06fg	57.00g	9.82h	41.02e	69.49f	1.83de	4.85i	12.3h	1.80g	5.82f	12.04g

Values having the same alphabetical letter (s) did not significantly differ at 0.05 level of significance, according to **Duncan's** multiple range test.

significant differences among the treatments at all dates. Application of 400 ppm from salicylic acid had the highest values followed by ascorbic acid with 400 ppm at 30, 50, and 70 days from transplanting in both growing seasons.

Leaf area and total chlorophyll

Leaf area and total chlorophyll of sweet pepper at all dates in both growing seasons were significantly affected by the interaction between antioxidants and their concentrations Table 11. The interaction between salicylic acid and 400 ppm at all dates recorded the highest value for leaf area in both growing seasons. Interaction between ascorbic acid with 400 ppm, salicylic acid with 200 and 400 ppm and tocopherol with 200 ppm had the best value for total chlorophyll in both seasons.

It could be concluded that, the increase in vegetative growth characters caused by antioxidants may be due to the role of antioxidants intercept free radicals and protect cells from the oxidative damage that leads to aging and disease **(Wada and Ou, 2002; Karadeniz *et al.*, 2005).** Antioxidants play a role in the reduction or prevention of enzymatic reactions by inhibiting polyphenol oxidase **(Maurice *et al.*, 2000).**

Salicylic Acid (SA) is a growth regulator which participates in the regulation for physiological and biochemical processes in plants (**Bhupinder and Usha, 2003**). It is an endogenous hormone which stimulates plant growth and is associated with increased amount of water content in the plant cell **(Hayat *et al.,* 2010).** Foliar application of SA is also involved in stomata regulation thereby can work the controlling to photosynthetic rate, consequently, enhanced photosynthesis, also it increased sap production in the leaf lamella which resulted in maintenance of relative water content in leaf and better growth **(Khan *et al.*, 2003; Hayat *et al.*, 2010). Pacheco *et al.* (2013)** suggested that the observed increase in photosynthesis rate in plants sprayed with SA can be assigned to metabolic changes at the chloroplasts level (efficiency of photosystem II and Rubisco enzyme activity).

These results are in agreement with those obtained by **Fathy *et al.* (2000)** on eggplant who mentioned that salicylic acid increased plant height, number of branches and leaves per plant and plant dry weight. Previous studies have demonstrated that wide range of responses might appear after exogenous SA application as follows: increases in tomato plant height, number of flower branches and number of leaves **(Ali *et al.*, 2009).**

Yildirim and Dursun, (2009) on tomato mentioned that lower SA concentration increased plant height, number of branches, leaves per plant and dry weight. Also, many researches come to similar results **(Akbarimehr *et al.*,** 2013 on sweet pepper; **Kazemi, 2014** on tomato; **Abdul Qados, Amira, 2015** on sweet pepper and **Abd El-Gawad and Bondok, 5015)** on tomato.

The positive effects of SA could be attributed to the increase of Co_2 assimilation and photosynthetic rate, and increase of mineral uptake by stressed plant under SA treatment **(Khan *et al.*, 2003; Szepesi *et al.*, 2005).** Some researches indicated that salicylic acid increases membrane permeability and that would facilitates absorption and utilization of mineral nutrients and transport of assimilates **(Javaheri *et al.,* 2012).**

Salicylic acid acts as one of antioxidant substances concentreated in the chloroplast and protect the photosynthetic apparatus when a plant is subjected to stress, by scavenging the excessively free redicals (ROS) **(Sreenivasulu *et al.*, 2000).** These results are in agreement with those obtained by **Canakci (2011)** who found that 1.5 mM concentration of salicylic acid had a stimulating effect on growth, dry weight and protein of pepper as compared with other concentrations (5 and 10 mM).

Table (11): Effect of interaction between antioxidants and their concentrations (ppm) on leaf area and total chlorophyll reading (SPAD) of sweet pepper during 2012 and 2013 seasons.

Treatments	Characters	Leaf area/ plant (cm^2)			Total Chlorophyll Reading (S		
		Days after transplanting					
		30	50	70	30	50	70
					First season (2012)		
Ascorbic Acid	0.0	233.5j	924.2h	1852.6f	65.53g	66.83de	66.76gh
	200	372.7cd	1810.9cd	3602.0c	70.56b-d	72.00bc	72.63cd
	400	441.5b	2102.5b	4101.4b	72.43a-c	74.20ab	75.03b
	600	304.5gh	1689.5de	3015.1d	69.53de	71.10c	71.43de
Oxalic acid	0.0	231.1j	931.9h	1827.5f	65.80g	65.00de	66.46h
	200	331.59fg	1488.9fg	2433.9e	69.73de	67.40d	69.16f
	400	281.3hi	1403.1g	2145.9ef	68.10ef	67.23de	68.26fg
	600	264.2i	1484.8fg	1998.7f	68.26d-f	65.95de	66.93gh
Salicylic Acid	0.0	230.5j	933.4h	1866.4f	65.20g	66.83de	66.40h
	200	400.2c	2036.8b	4025.6b	72.70ab	73.80a-c	73.93bc
	400	514.8a	2529.2a	5086.8a	74.33a	75.23a	76.93a
	600	339.6ef	1790.6cd	3089.6d	70.06de	72.56a-c	71.96de
Tocopherol	0.0	229.2j	914.7h	1869.6f	66.70fg	64.36e	66.90gh
	200	366.8de	1852.2c	3324.4d	72.76ab	71.06c	72.33de
	400	339.9ef	1698.3de	3143.1d	70.23c-e	71.29bc	71.96de
	600	355.6def	1584.3ef	3075.5d	68.96d-f	71.43bc	70.90e
					Second season (2013)		
Ascorbic Acid	0.0	236.4h	955.7g	1834.4f	65.43g	66.13h-j	67.86d-g
	200	371.5e	2064.9d	3143.0d	70.40cd	71.13cd	72.56bc
	400	471.8b	2363.2b	3975.3b	72.45a	72.33bc	75.10a
	600	357.8e	1907.8e	2886.6d	69.72de	70.10d	71.36c
Oxalic acid	0.0	230.5h	973.3g	1828.8f	65.73g	66.60g-h	66.53fg
	200	352.8e	1796.7e	2317.5e	68.43ef	67.66f-h	69.40d
	400	305.7f	1545.6f	2115.4e	68.20ef	68.36ef	68.33d-f
	600	272.6g	1457.7f	1822.9f	67.20f	68.06fg	69.02de
Salicylic Acid	0.0	242.6h	990.0g	1802.5f	64.96g	64.66j	65.90g
	200	429.2c	2336.3b	3631.6c	71.86a-c	72.90ab	74.33ab
	400	558.9a	2799.5a	4729.2a	73.23a	74.06a	76.16a
	600	359.6e	2065.4d	2889.1d	70.66b-d	71.03cd	71.73c
Tocopherol	0.0	240.6e	1024.8g	1673.2f	65.46g	65.66ij	67.16e-g
	200	401.8d	2312.5bd	3088.2d	72.00ab	72.46bc	74.46ab
	400	382.5de	2190.6c	3013.7d	70.46b-d	70.32d	72.38bc
	600	381.4de	2038.6d	2882.5d	69.40de	69.73de	72.00c

Values having the same alphabetical letter (s) did not significantly differ at 0.05 level of significance, according to **Duncan's** multiple range test.

In addition, some researchers reported that the highest plant growth and number of braches values were obtained from the ascorbic acid foliar application **(Shabana, Abeer *et al.*, 2015** on sweet pepper; **El-Hifny and El- Sayed, 2011** on sweet pepper **and Ghurbat, 2013)** on pepper plant. These increases in the above parameters by using ascorbic acid may be due to the fact that ascorbic acid as an antioxidant has an effect as plant growth regulators **(Johnson *et al.,* 1999)** and its role in activating both cell division and elongation in meristematic tissues, as well as the biosynthesis of organic foods **(Nijjar, 1985).** The beneficial effect of ascorbic acid (Vitamin. C) on plant height may be attributed to the fact that ascorbic acid (Vitamin. C) is involved in the regulation of shoot and root elongation, cell vacuole, leaf area and cell expansion **(Sumalan and Carmen, 2002; El Hariri *et al.,* 2010; Farahat *et al.,* 2013).**

The stimulating effect of ascorbic acid on plant growth may be attributed to an increase in availability and uptake of water and essential nutrients through adjusting cell osmotic pressure, and reducing the accumulation of harmful free radicals (ROS) by increasing antioxidants and enzyme activities **(Farouk *et al.,* 2011)**. In addition, they indicated that the positive effect of ascorbic acid on plant growth may be due to its effect on increasing nutrient uptake and increase elements content such as nitrogen, phosphorous, and potassium. Phosphorous and potassium are essential nutrients playing an important role in the biosynthesis and translocation of carbohydrates, and necessary for stimulating cell division, cell turger and forming DNA and RNA **(Saeidi-Sar *et al.*, 2013).**

These results are in agreement with those obtained by **(Azooz and Al-Fredan, 2009; Ekmekçi and Karaman, 2012)** who indicated that, vitamins (such as ascorbic acid) could accelerate cell division and cell enlargement and induce improvement of membrane integrity, which may have contributed in reducing ion leakage, and consequently improving growth. Many studies have reported that vitamins, when used with optimal concentration, exhibited beneficial effect on growth and yield of some crop plants grown under saline conditions **(Khan *et al.*, 2011; Ekmekçi and Karaman, 2012). Wassel *et al.* (2007)** assumed that the effect of ascorbic acid on the plant growth might be due to the auxinic action of Ascorbic acid as well as, its improved role in many metabolic and physiological processes and enhancing the synthesis of carbohydrates.

The promoting effect of SA on the leaf area was attributed to its important roles on activating cell division and the biosynthesis of organic foods. In addition, **Raskin (1992)** mentioned that enhancing effect of SA on the availability and movement of nutrients could result in stimulating different nutrients in the leaves. **Gharib (2006)** on basil and marjoram and **Khan *et al.* (2003)** on corn and soybean reported that application of SA enhanced photosynthesis rate, so that leaf area has been increased. The present results are in agreement with those of **Abou El-Yazeid, (2011)** on sweet pepper; **Abdul Qados (2015)** on sweet pepper under salt stress conditions, **Shabana *et al.* (2015)** on sweet pepper; and **Kazemi (2013)** on strawberry.

Exogenous SA alters the activities of antioxidant enzymes and increases plant tolerance to abiotic stress by decreasing generation of ROS. It has been found that SA has different effects on stress adaptation and damage development of plants that depend on plant species, concentration, method and time of SA application **(Metwally *et al.*, 2003). Kazemi (2014)** on tomato found that using low SA (0.5 m $molL^{-1}$) concentrations alone significantly increased chlorophyll content. Also, **Gharib**

(2006) on basil and **Yildirim and Dursun (2009)** on tomato mentioned that lower SA concentration increased plant height, chlorophyll content, number of branches, leaves per plant and dry weight.

The increase in total chlorophyll under low levels of salinity recorded in this study is in agreement with the finding of **Hussein *et al*., (2012)** on pepper plants and **Lui *et al*., (2007)** on *Aeluropus littoralis* plants who found that salt stress increased Chl a and Chl b contents, but the Chl a/Chl b ratio declined, which implies the stimulation of Chl a accepted from NaCl was smaller than that of Chl b. This increase may be attributed to the thickness of the leaves under salt stress rather than to stimulation of pigment formation.

On the other hand, ascorbic acid can mitigate the adverse effects of stress through increasing the content of IAA and GA3 and decreasing ABA level, which may be involved in protecting the photosynthetic apparatus and consequently increasing the photosynthetic pigments **(Saeidi-Sar *et al.*, 2013).** Consequently, in ascorbic acid treated plants, high level of carotenoids can synergistically function with ascorbic acid to provide an effective barrier against oxidation under salinity stress. These results reinforce the results obtained by other investigators **(Azooz and Al-Fredan, 2009)** who concluded that, chlorophyll content of plants treated with vitamins (such as ascorbic acid) was increased due to the protection effect of these vitamins.

Azzedine *et al.* (2011) reported that, ascorbic acid can detoxify and neutralize the reactive oxygen species by prevention of free radicals activity, leading to increase in chlorophyll content of vitamin- treated plants. They also found that, application of vitamin C (ascorbic acid) was effective to mitigate the adverse effect of abiotic stress on plant growth due to increased leaf area and improved chlorophyll and carotenoids contents. On the contrary, **Pacheco *et al.* (2013)** observed that the chlorophyll content in SA treated marigold plants did not differ significantly from the control plants.

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الملخص العربي

تحسين إنتاجية الفلفل الحلو باستخدام بعض مضادات الأكسدة تحت ظروف الملوحة بجنوب سيناء:

١. صفات النمو الخضري

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أجريت تجربتين حقليتين في الموسم الصيفي لعامي ٢٠١٢، و٢٠١٣ في المحطة البحثية برأس سدر بجنوب سيناء والتابعة لمركز بحوث الصحراء، كان الهدف الرئيسي هو دراسة تاثير بعض مضادات الأكسدة على النمو الخضري لمحصول الفلفل هجين صنف " سونار"، تم الرش بمحلول من مضادات الأكسدة التالية: حمض الأسكوربيك (فيتامين ج)، وحمض الأوكسالك، وحمض السلسيلك، والتيكوفيرول (فيتامين هـ) وذلك باربع تركيزات من كل من هذه المواد وهي: بدون رش، و٢٠٠ppm، و٤٠٠ppm ، و٦٠٠ppm، وتم رشها بعد ٢٠، و٤٠، و٦٠ يوماً بعد الشتل، أوضحت النتائج أن أعلى القيم لصفات النمو الخضري المتمثلة في ارتفاع النبات، وعدد الفروع وعدد الأوراق للنبات، والوزن الطازج والوزن الجاف للنبات، والمساحة الورقية للنبات، بالإضافة إلى الكلوروفيل الكلي، حيث تأثرت كلها معنوياً بالرش بمضادات الأكسدة، وكانت أعلى القيم عند الرش بحمض السلسيلك، وحمض الأسكوربيك بتركيز ٤٠٠ جزء في المليون من أي منهما.

الكلمات الاسترشادية: الفلفل الحلو، مضادات الأكسدة، الملوحة، جنوب سيناء، صفات النمو الخضري.

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